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MEMORANDUM FOR IRVING McCRAE
Contracting Officer, Acquisitions Management Division
MSHA - Headquarters, Arlington

THROUGH: KELVIN K. WU
Dam Safety Officer

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FROM: JAMES B. PFEIFER
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SUBJECT: Summary of TDEM Geophysical Void Detection Demonstration Project by D'Appolonia Engineering Division of Ground Technology, Incorporated, Mine Void Detection Project Account Number B2532538, MSHA RFP No. J53R1011

D'Appolonia Engineering Division of Ground Technology (D'Appolonia) has recently completed the demonstration of the time domain electromagnetic (TDEM) geophysical method to detect underground mine voids along the perimeter of a coal waste impoundment. The project was performed under account number B2532538 in connection with MSHA RFP No. J53R1011. As the Contracting Officer's Technical Representative (COTR) for this project, I was responsible for monitoring and reporting on D'Appolonia's performance on behalf of the Contracting Officer. This memorandum is intended to provide a general summary of the completed project and a discussion of the final results.

PROJECT OBJECTIVES AND TASKS

The main objective of the project was to demonstrate the use of the TDEM geophysical survey method to detect the presence of underground mine voids at several locations along the perimeter of Pine Ridge Coal Company's Lots Branch Impoundment, MSHA I.D. No. 1211-WV04-00020-01. More specifically, the project consisted of the following tasks:

- Preparation and presentation of a Work Plan. The specifics of the survey methods, survey locations, exploration drilling program, downhole imaging, and special access and safety precautions were detailed in the Work Plan. The Work Plan was submitted in April, 2005. Prior to preparation of the Work Plan, short test surveys were performed. The short test surveys were inconclusive due to equipment malfunctions. Prior to conducting subsequent tests a calibration procedure was followed each day to ensure that the equipment was working properly.

- Performing the main TDEM geophysical surveys. The main geophysical surveys were conducted in May 2005 using a PROTEM-47 system with a 5-meter multi-turn transmitter loop manufactured by Geonics Limited. The TDEM surveys were taken at 5 meter spacings along four profiles (TD-1 through TD-4) covering slightly more than 6,000 lineal feet. The four survey lines traversed existing mine access roads or old logging roads and were situated so that they passed over abandoned mine workings in close proximity to the impoundment and over exposed mine portals. Location and elevation surveys were also performed to accurately locate the traverses, existing mine portals, and mine discharges. The locations of the mine portals shown on the mine maps were compared to the surveyed locations and D'Appolonia determined that the mine maps should be shifted approximately 50 feet east and 25 feet north. D'Appolonia also performed DC resistivity surveys at the site. A portion of the DC resistivity survey results are presented in the TDEM final report for comparison purposes. Detailed results of the DC resistivity survey are presented in a separate report prepared by D'Appolonia.

  Prior to the field demonstration, D'Appolonia estimated the subsurface conductivity measurements through forward modeling. Computer software was used to analyze the subsurface conditions using estimated electrical properties for the strata and mine voids. The results of the forward modeling suggested that the TDEM technique could be effective for mapping flooded workings deeper than about 100 feet in settings representative of eastern coal fields.

- Processing and interpretation of the geophysical survey data. Field measurements were converted to a format that could be read by the computer inversion programs and obviously inaccurate data was deleted from the set. The software was used to create a layered-earth model at each sounding location (every 5 meters) and a 2-dimensional geo-electric cross-section was generated. The computer software was then used to generate the colored cross sections that depict the measured variations in electromagnetic properties that are presented in the Figures section of D'Appolonia's final report.

- Four core holes and 24 air rotary borings (boreholes) were drilled between September 15, 2006 and September 21, 2006. The drill locations were based on the results of the geophysical surveying (both TDEM and resistivity). The depth of water at each drill location was checked using an M-scope water level indicator. No measurable amounts of water were observed in the borings that intersected the mine voids. The mine voids were characterized as moist to wet based on the M-scope response and observation of sediments.

  Laser imaging was conducted at four locations where the boreholes intersected the mine workings. High-resolution laser images were obtained using a downhole geometric scanner (Ferret) developed by Carnegie Mellon University and commercialized by Workhorse Technologies, Incorporated. A 3-dimensional point cloud model was generated in the field from the laser data. The point cloud was then converted to a mesh model to allow the viewing of the subsurface void space. A detailed description of the results of the laser imaging is presented in Appendix A of the final report.

  The boreholes were filled with grout at the completion of the laser imaging. Borings and core holes that intersected the mine voids were plugged prior to grouting.

- Preparation and submittal of the draft and final reports. A draft of the final report was submitted for peer review in January 2006. Review comments were forwarded to D'Appolonia and the final report was submitted in July 2006.

THEORY OF TDEM

Electromagnetic geophysical surveying was developed to locate areas of high conductivity. To obtain measurements of subsurface conductivity, a transmitter sends an alternating current through a loop of insulated electrical cable laid on the ground. The current flow is gradually turned on and off (ramp time) which creates a changing magnetic field and the changing magnetic field induces an electrical field in materials that attempts to oppose the change. The induced electric field then creates a secondary electromagnetic field. The current system diffuses outward and downward and the diffusion rate is dependent on the conductivity of the nearby targets. The diffusing, time-varying current produces time-varying secondary magnetic fields. The decaying magnetic fields produce time-varying voltage in the receiver coils that are located on the ground surface.

SITE DESCRIPTION

Underground mining (room and pillar) in the Lewiston coal seam took place between the 1930's and the 1950's. The mine entries are approximately 20 feet wide and the thickness coal seam thickness ranges from 4 to 6 feet. At the TDEM survey locations, the thickness of the overburden above the Lewiston coal seam ranged between 25 feet and 60 feet. The strata above and below the Lewiston coal seam is predominately sandstone with some relatively thin layers of shale and coal. The coal seam dips towards the northwest at about 1.5 degrees and outcrops in the area of the impoundment between elevations 1460 feet and 1540 feet. The proposed future elevation of the fine coal refuse in the impoundment is 1495 feet. The mine workings and portals in the Lewiston coal seam will be covered at several locations around the perimeter of the pool area when the slurry pool is raised to elevation 1495 feet.

DISCUSSION OF RESULTS

Survey Line TD-2:

There were no mine workings indicated on the mine maps where line TD-1 was run. The TDEM results did not suggest that there were any mine voids at the level of the Lewiston coal seam. The results did show a resistivity low in the upper 10 to 20 feet which was unexpected given that the strata was competent rock. DC resistivity results along this line did not verify the resistivity lows suggested by the TDEM. No borings were drilled at the location of survey line TD-1.

Survey Line TD-3:

The mine maps indicate that abandoned coal mine workings are present under survey line TD-3 from approximate stations 0+00 to 11+10, 12+80 to 16+25, 18+60 to 19+60, and 28+10 to 29+45. The TDEM results suggest that workings are only present at one localized area at station 15+40 and between stations 18+20 and 19+90. Four borings (B-14 through B-17) were drilled between stations 18+90 and 19+90. None of these borings intersected the two entries shown on the mine maps. Boring B-18, which was drilled at station 14+60, intercepted a mine void.

Survey Line TD-1:

The mine maps indicate that workings may be present under survey line TD-1 from approximate stations 6+50 to 9+25, 13+50 to 13+95, and 17+70 to 19+30. The TDEM results suggest that workings are present between stations 7+65 and 8+65. The TDEM results also show resistivity lows in the upper few feet of the strata in two areas where such readings would not be expected. Three borings (B-6 through B-8) were drilled between stations 6+55 and 8+95 and seven borings (B-3, B-4, and B-30 through B-34) were drilled between stations 12+50 and 13+85. Boring B-5 was drilled at station 11+35 and borings B-1 and B-2 were drilled at stations 18+25 and 18+95. Borings B-6, B-7, and B-8 hit relatively thin air voids and mine gob (roof fall material) at the elevation of the Lewiston coal seam. Borings B-30 and B-31 penetrated the mine workings. The remaining borings along survey line TD-1 hit solid coal (no workings) at the elevation of the Lewiston coal seam.

Survey Line TD-4:

Survey line TD-4 was relatively short and passed over 2 exposed mine entries. Because the mine dips away from this area, it was anticipated that these workings would not be detectable by TDEM techniques, since they voids were expected to be dry. Although the mine workings were relatively shallow in this area (28 feet deep), the TDEM technique was not able to image the workings.

Laser Imaging:

High resolution laser imaging of the mine voids was done at four borehole locations. Distance measurements extended as far as approximately 120 feet from the laser, depending on the location of the borehole relative to the mine void. Based on the distances measured by the laser imaging, the volume and orientation of the void space could be calculated. Generally, the laser imaging confirmed the orientation of the mine voids and at boring B-31, it appears that a cross cut that was not shown on the mine maps was imaged.

The Ferret could not be used at boring B-11 because a buildup of drill cuttings on the mine floor reduced the height of the void space to approximately 1 foot. Additionally, the Ferret could not be lowered into the mine workings at boring B-18 either because the borehole was misaligned or there was an obstruction at a depth of approximately 24 feet.

CONCLUSION

Because the Lewiston coal seam dips towards the northwest, it was anticipated that the mine workings on the southern side of the hollow would be flooded or at least partially flooded. It was also anticipated that the mine water would be relatively acidic and highly conductive compared with the surrounding strata. Based on the results of the M-scope readings taken during the drilling portion of the project, the mine voids contained no measurable amounts of water and were characterized as moist to wet.

Therefore, the conditions were less than optimal for void detection using TDEM techniques.

The TDEM technique was only able to image areas of extensive mine workings in limited areas. These areas were not flooded but were characterized as moist or wet. At areas where the known workings were dry, the method yielded little results that would suggest the presence of mine workings. The results also indicated areas of low resistivity in some areas where these readings would not be expected. It did not appear that the degree of resolution of this technique was high enough to detect individual mine entries.

Although D'Appolonia indicates in their final report that theoretical modeling and tests run at another mine site suggest that the TDEM technique would be capable of detecting flooded mine workings, this could not be verified on the basis of their demonstration project.

While not a method for detecting voids from the ground surface, the downhole laser imaging performed by Workhorse Technologies, Incorporated, proved to be an effective tool for determining the size and orientation of mine voids which were penetrated by boreholes. The laser imaging was used to detect mine workings that were not shown on the mine map.

Please contact us at 412-386-6810/4470 if there are any questions regarding this memorandum.

cc: D. Chirdon – General Eng., TS